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As part of the Coastal Mixing and Optics Accelerated Research Initiative, measurements of density, light absorption/attenuation and microstructure were made using sensors mounted on a towed undulating platform. The sensor suite included a conductivity-temperature-depth instrument, a nine-wavelength spectral absorption and attenuation meter, and a new microstructure instrument. Surveys were conducted during August 1996 and April-May 1997 in the Middle Atlantic Bight near 40.5N, 70.5W. Time-dependent maps of the three-dimensional distributions of hydrographic, velocity and optical properties over the shelf and slope showed the importance of mesoscale and sub-mesoscale features. Evidence for secondary circulation associated with a shelfbreak front, an important process for frontal formation/maintenance and the vertical flux of nutrients, was obtained by jointly analyzing the hydrographic, optical and velocity data. Microscale conductivity fluctuations measured with a new high-frequency turbulence measuring instrument were used to determine temperature dissipation rate, the Cox number and the scaler diathermal turbulent diffusivity. Observed diffusivities near the shelfbreak front were two orders of magnitude larger than mid-ocean thermocline values. The multi-wavelength light absorption measurements were decomposed into contributions from the major absorbing components of seawater: phytoplankton, gelbstoff and tripton. The inherent optical property distributions were, to first-order, controlled by the physics.

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Rapid Hydrographic, Optical and Microstructure Surveys on the Continental Shelf and Slope

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As part of the Coastal Mixing and Optics (CMO) Accelerated Research Initiative, we made contemporaneous measurements of density, light absorption/attenuation and microstructure using sensors mounted on SeaSoar, a towed undulating measurement platform. The SeaSoar sensor suite included a dual-sensor Sea-Bird conductivity-temperature-depth (CTD) instrument, a nine-wavelength spectral absorption and attenuation meter (WETLabs ac-9) and a new microstructure instrument (MicroSoar). Horizontal velocity was measured using a 300-kHz shipboard acoustic Doppler current profiler (ADCP). We conducted rapid surveys using R/V Endeavor during two 21-day field experiments in the Middle Atlantic Bight centered near 40.5°N, 70.5°W, south of Cape Cod. We completed a summer survey, when the shelf is stratified, from 14-Aug to 1-Sep 1996 and a spring survey, when the shelf water tends to be more mixed, from 25-Apr to 15-May 1997. During each field experiment we collected data from repeated large-region surveys over a roughly 70 x 80 km box completed in about 2 days. Alternating with the large-region surveys, measurements were concentrated in a small box (roughly 25 x 25 km completed in 14 hours) centered around a mid-shelf location where the physical and optical fields were intensively sampled by our CMO colleagues using moored instrumentation and vertical profiling from a stationary ship.

We processed data from the instruments aboard SeaSoar which made approximately 34,900 vertical profiles of the water column over the continental shelf and slope during the CMO cruises. Hydrographic fields obtained from the CTD onboard SeaSoar were reported in O'Malley *et al.* (1998), an online version of of which can be found at http://diana.oce.orst.edu/cmoweb/csr/main.html. All CTD data were submitted to the National Oceanographic Data Center (NODC).

Velocity data from the ADCP were processed using bottom tracking, DGPS ship's navigation and high-quality ship's heading from the R/V Endeavor's TANS system, and were reported in Pierce *et al.* (1998), online at http://diana.oce.orst.edu/cmoweb/adcp/main.html. All ADCP data were submitted to the Joint Archive for Shipboard ADCP (JASADCP). Velocity data from our two 21-day CMO cruises together with moored velocity data from Levine and Boyd (SAS PRIMER, Jul-Sep 1996), Pickart (Shelfbreak PRIMER, Dec 1995 to Feb 1997), and Beardsley and Gawarkiewicz (Shelfbreak PRIMER, Jul-Aug 1996) were used to estimate barotropic tidal currents in the CMO region. Five tidal constituents (M2, S2, K1, O1, and N2) were fit in time and space to the velocity data using a least-squares harmonic model with cubic surface-fitting Chebyshev polynomials (101 unknowns). A singular value decomposition was used to solve this possibly rank-deficient inverse problem. Two improvements on the published methods are: different levels of uncertainty associated with each input velocity data point (e.g., bottom-tracked vs. navigation-referenced ADCP) are explicitly taken into account to produce a properly weighted solution; and Chebyshev rather than ordinary polynomials are used as the basis functions, offering numerical advantages and

greater accuracy for under-determined cases.

MicroSoar data from the fast-response capillary microconductivity probe sampling at 2 kHz, from co-located temperature and pressure sensors, and from a three-axis accelerometer have been processed. Details of the MicroSoar design appear in May (1997) and a description of the MicroSoar system and techniques for obtaining fields of temperature variance dissipation rate (chi), Cox number and heat flux is in Dillon *et al.* (2001). The entire CMO MicroSoar data set, including vertical sections and horizontal maps of microstructure properties, has been reported in Erofeev *et al.* (1998), online at http://diana.oce.orst.edu/cmoweb/micro/main.html. The MicroSoar technology is being packaged for use by R. Zaneveld (OSU), D. Hebert (URI) and C. Paulson and H. Wijesekera (OSU).

Processing of optical data from the nine-wavelength absorption and attenuation meter (WETLabs ac-9) flown aboard SeaSoar required new processing techniques. It is critical to calculate a time-dependent lag between when the optical properties were measured and when the CTD sensors sampled the same water parcel so that the optical data can be corrected for known dependence on temperature (and to a lesser extent on salinity) (Barth and Bogucki, 2000). A report of the optical data set was published (Simeon *et al.*, 2000), a subset of which is available online at http://diana.oce.orst.edu/cmoweb/ac9/main.html. The optical data set has been submitted to the World Ocean Optical Database (WOOD). The MODAPS+ data acquisition and power supply system, developed in part in response to the needs of the ac-9 on SeaSoar application, is being used by others (T. Cowles, OSU; C. Roesler, Bigelow) and is available from WETLabs, Inc.

Time-dependent maps of the three-dimensional distributions of hydrographic, velocity and optical properties over the shelf and slope in the Middle Atlantic Bight south of Cape Cod showed the importance of advection and mesoscale (with horizontal dimensions of the size of the Rossby radius) and sub-mesoscale structure on vertical distributions at a mid-shelf location. Examples include intrusions from offshore at both the bottom and near the surface of warm, salty and relatively clear slope water, mesoscale meanders from the shelfbreak front and jet, and packets of internal solitary waves propagating shoreward with attendant significant displacement of the thermocline and deep chlorophyll maximum at the base of the pycnocline. The spring 1997 cruise captured the restratification of the water column and an anomalous shoreward extent of a warm, salty bottom boundary layer driven by eastward near-bottom flow likely associated with a backward-breaking unstable meander of the shelfbreak front and jet.

Evidence for secondary circulation associated with a shelfbreak front was obtained from a high-resolution, cross-shelf section of hydrographic, optical and velocity fields (Barth *et al.*, 1998). Convergence in the bottom boundary layer on the inshore side of the front and subsequent upwelling into the interior was evident by a mid-water region of suspended bottom material emanating from the foot of the front (40.35N, 85-m isobath) and extending to within 35 m of the surface, 80 m above bottom. Downwelling on the offshore side of the front in the upper water column is inferred from a 20-m downward bend of the subsurface phytoplankton layer. These were the first direct observations confirming model predictions for secondary circulation near an idealized shelfbreak front. Convergence in measured cross-shelf velocity at the foot of the front is consistent with upwelling of bottom material detected

there. An estimate of 9 ± 2 m day^{-1} of upwelling on the inshore side of the shelfbreak front was obtained, implying a transit time from the bottom to the surface of 10-16 days. This secondary circulation has important implications for the biogeochemistry of shelfbreak fronts through upwelling of nutrients into the euphotic zone and concentration of material on the offshore side of the front.

The barotropic tide in this region is dominated by the M2 and K1 constituents, with 65% and 12% of the total tidal variance. The size of the M2 varies strongly across the region, with semi-major axes of 0.30 m s^{-1} at the northeast corner (40.7N, 70.0W) but decreasing to 0.02 m s^{-1} at the southwest corner (39.9N,71.0W). The M2(K1) solutions have accuracies of 0.016(0.026) m s^{-1} rms, validated independently by comparison with current meter data omitted from the model. After subtraction of the best barotropic tidal estimate, we also re-applied the method to the residual, in order to examine the baroclinic tidal signature. The barotropic tidal prediction is also used to produce subtidal velocity fields from the measured shipboard ADCP velocities, revealing the details of the frontal jets and eddies over the shelf and slope.

Particulate resuspension induced by internal solitary waves (ISW) during the 1996 CMO experiment was reported by Bogucki *et al.* (2001). ISW-induced resuspension was related to retarded flow under the wave footprint and corresponded to the largest resuspension events observed in the experiment. Both mode-1 and mode-2 ISWs were observed. The mode-2 waves appear to be locally generated by mode-1 ISWs. They arrived at the mooring site from a variety of sources, though a common intermodal dynamics seemed to occur repeatedly. To our knowledge, these are the first observations of mode-2 waves on the continental shelf. Both mode-1 and mode-2 ISWs were responsible for resuspension. This situation may be common for other shallow seas.

Dillon *et al.* (2001) described the details of a new high-frequency turbulence measuring instrument, MicroSoar. With appropriate assumptions about the local T-S relation, measurements of microscale conductivity fluctuations can often be used to directly determine temperature dissipation rate, the Cox number and the scaler diathermal turbulent diffusivity. Compared with conventional quasi-free-fall tethered vertically profiling instruments, MicroSoar's major advantage lies in its ability to sample large fluid volumes and large geographic areas in a short time. A cross-shelf section in the Middle Atlantic Bight south of Cape Cod, Massachusetts, revealed springtime restratification of the surface layer over cold shelf water bounded on the offshore side by the stratified shelfbreak front. The temperature variance dissipation rate indicated strong mixing at the base of the surface mixed layer and at the seasonal thermocline. A branch of the high dissipation rate in the thermocline deepens and connects with very high dissipation rates near the bottom. Cox numbers were large near the shelfbreak front and diffusivities were as large as 10^{-3} m^2 s^{-1}, two orders of magnitude larger than mid-ocean thermocline diffusivities.

The multi-wavelength light absorption measurements made from the WETLabs ac-9 onboard SeaSoar were decomposed into contributions from the major absorbing components of seawater: phytoplankton; gelbstoff or colored dissolved organic material (CDOM); and colored particulate material or tripton (Simeon, 2000; Simeon *et al.*, 2001). The decomposition used a new iterative, least squares formulation that minimizes the residuals, subject to the constraint that the solution be non-negative. Seasonal changes in the density struc-

ture redistribute major light-absorbing components. In summer, strong stratification leads to significant vertical and cross-shelf structure in the optical properties while in spring, the thick surface and bottom mixed layers lead to more uniform optical property distributions punctuated by patches of phytoplankton and tripton. In both seasons, the horizontal inherent optical property distributions reflect the first-order control of the physics, in particular the shelfbreak front. To bound the spatial scales for which optical tracers can be utilized, horizontal decorrelation lengthscales (L) were calculated for the hydrographic and optical parameters. Temperature and salinity have decorrelation length scales of 15-20 km within and above the summer pycnocline, below which L linearly decreases to < 5 km near the bottom. This decrease reflects the stabilizing influence of the sloping bottom topography as it constrains the horizontal variability of the foot of the shelfbreak front. Decorrelation lengthscales for beam attenuation and component light absorption at 440 nm follow closely those for the temperature and salinity below 60 m, but are shorter (L = 5-10 km) in the upper water column because of biological processes present there. In spring, the decrease of decorrelation lengthscale with depth is again evident, but now the upper-ocean (depths < 80 m) lengthscales in both the physical and optical properties are shorter (L = 10-15 km) and more similar to each other than in summer.

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